Transplantation and Alteration of Submarine Environment for Restoration of *Zostera marina* (eelgrass): A Case Study At Curtis Wharf (Port of Anacortes), Washington

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Abstract
Using a blend of restoration techniques, we have altered the nearshore zone on the southern side of Guemes Channel so that an *in situ* eelgrass (*Zostera marina*) population has expanded (rhizomal) and new patches are forming (seed dispersal). Our project was initiated to mitigate the effect of dock shading by joining two adjacent commercial docks. In response to the requirement by the Washington Department of Fish and Wildlife, we concluded that a blend of small-scale, low-cost, restoration techniques to enhance the eelgrass zone immediately adjacent to the project would meet protection goals. Our plan required that:

1. Historically deposited rubble and debris (e.g., concrete blocks, wire cables, metal fencing and rubber hose) be removed from the eelgrass zone.
2. A section of dock that shaded the substrate be removed.
3. Reflective panels be installed to alter submarine light under existing dock.
4. Eelgrass plants from the proposed construction area be transplanted to debris-free site.
5. Changes in eelgrass cover be monitored over three years. We recommend that this approach be considered at other sites in the Puget Sound Basin.

Introduction
Developing restoration designs that integrate efficient plant community expansion with cost-effective restoration methods may encourage the implementation of such methods. A combination of low-cost habitat enhancement treatments and naturally occurring rhizomal expansion and seed dispersal mechanisms were applied to enhance an existing population of eelgrass (*Zostera marina*) adjacent to an actively used commercial dock, Guemes Channel, Anacortes, Washington. Guemes Channel, located within northern Puget Sound, is an active route for anadromous fish traveling between the freshwater streams of western Washington and the Pacific Ocean (Kruckeburg 1991) (Figure 1). Chinook salmon, locally listed as endangered, are one of the anadromous fish species found to use vegetated tidal habitat for protective habitat and feeding (Shreffler and others 1992; Sheffler and Thom 1993). In addition, crab and other mollusk and fish species require eelgrass meadows for habitat (Thom 1987).

Under the appropriate environmental conditions, eelgrass can reproduce sexually (seed dispersal) and asexually (rhizomatously) (Harrison and Durance 1992; Phillips and others 1983). Restoration of eelgrass meadows has largely focused upon transplantation of whole plants into areas that either once maintained an eelgrass population or into an area designated by the landowner as a potential mitigation site, whether or not it historically maintained eelgrass (Fonseca and others 1998). Due to the no-net-loss policy

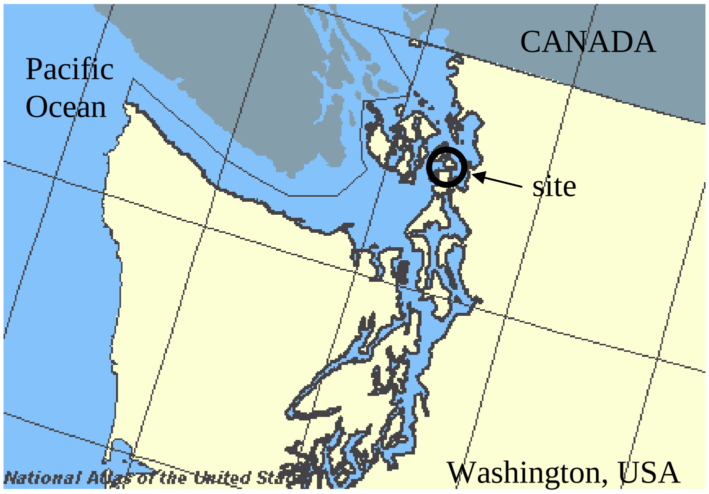

Figure 1. Regional Map

Within the state of Washington, eelgrass has become a highly visible resource requiring attention. Because Washington State's Department of Fish and Wildlife (Fish and Wildlife) is critical of restoration projects, those individual projects that require permits for nearshore activity are having to demonstrate successful establishment of marine populations prior to the granting of certain permits. In this case, low-cost, site-specific methods that achieve success are gaining the attention of those who must demonstrate success prior to receiving a permit. This is especially true when proposed activities may change between the initiation of a restoration project and its successful completion.

In 1996, the private owner of the Curtis Wharf and Gravel docks was required by Fish and Wildlife to move a small population of *Z. marina* from an area proposed to be covered by new dock construction. The proposed dock construction was to join the two existing docks while extending farther towards deep water for eventual use as an active commercial dock capable of off-loading deep draft cargo vessels. Upon site reconnaissance, an area to the south of Gravel dock was identified as having potential for *Z. marina* restoration, which would include the transplantation of the limited population impacted by new construction activities (Figure 2).

In negotiations between the private owner and Fish and Wildlife, mitigation goals were defined. The mitigation effort was to restore the area to the south of the existing docks in such a way that it would provide a minimum 117 m^2 (1300 $ft.^2$) of new *Z. marina* habitat, and support a community with an average shoot density similar (at least 80% of that within the impacted area) with the impact site (25 shoots/m^2). Mitigation success would be determined after the third year of monitoring.

Commonly known anthropogenic disturbances to *Z. marina* that lead to its areal reduction are shading (e.g., dock structures, temporary boot moorage), nutrient overloading (leading to excessive algal growth), physical disturbance (e.g., boat anchors, dredging), and siltation (e.g., shoreline runoff, dredging) (Short and Wyllie-Echeverria 1996). What many of these have in common is that they change the environmental conditions of the area in which the plant grows. Recreating the environmental conditions that had once existed prior to disturbance and allowing *Z. marina* to naturally re-colonize the area is the restoration approach that we used for this project (Ewing 1995).

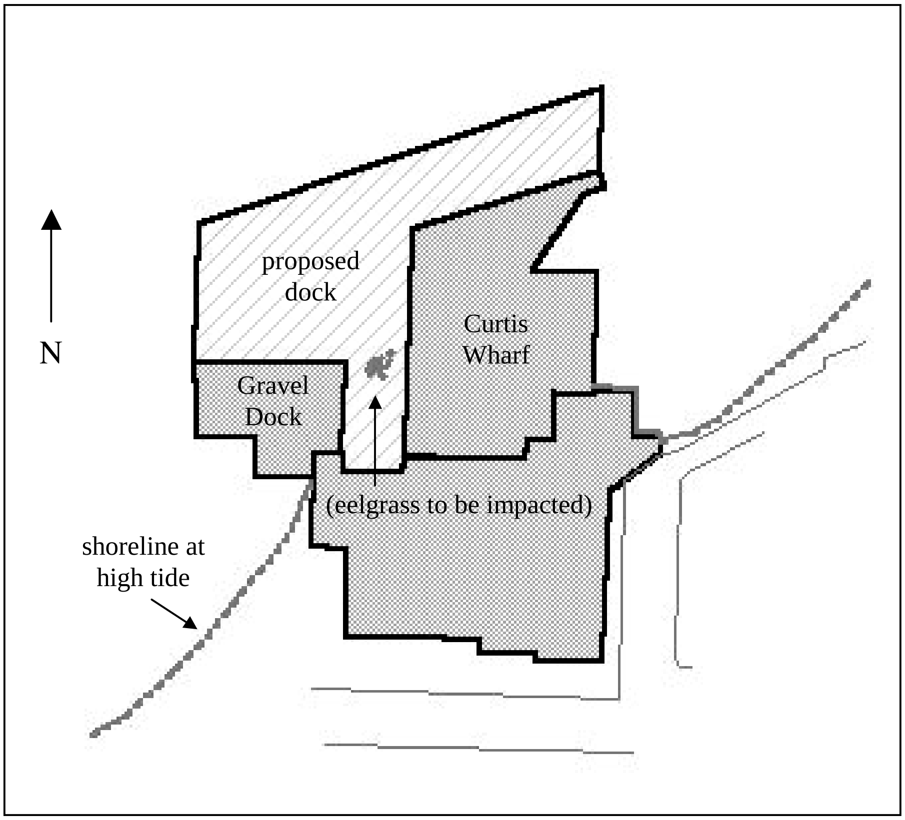

Figure 2. Site Map

Methods and Sampling Design

Alterations to Dock and Environment
Debris or rubble discarded within the intertidal and subtidal areas of *Z. marina* habitat limit the potential for expansion. The removal of debris/rubble from marine sediments was expected to create safe-sites for rhizomal growth and seed establishment of *Z. marina*. On 20 June 1997, the lowest tide of season, previously discarded construction debris/rubble was removed from 70 m^2 of intertidal and subtidal area south of Gravel dock to facilitate the natural recruitment and transplantation of *Zostera marina* var. *phillipsii* Backman (eelgrass) (Figure 3). Debris/rubble was removed using a track-hoe that traversed the exposed beach during the low tide. Where possible, the bucket of the track-hoe scraped the surface of the sediments to remove debris. In areas beneath the existing Gravel dock or beyond the reach of the arm and bucket, debris was collected by hand and loaded into the bucket for removal.

On June 23, 1997, a population of 100 *Z. marina* individuals (approximately 69 m^2 of sparsely populated subtidal area), to be impacted by the dock expansion project, was relocated to a 2.5 m^2 area not affected by construction. The transplant site was identified along the south side of Gravel dock where debris/rubble had earlier been removed (Figure 3).

The following criteria were used to select the transplant site:

1. The area had to be within the same ownership boundary as site of origin.
2. It had to have an elevation similar to site of origin.
3. Sediment characteristics had to be similar to site of origin.
4. No *Z. marina* could be present within the area to be transplanted. The selected site was devoid of *Z. marina* due to the existence of previous construction debris on the sediment surface.

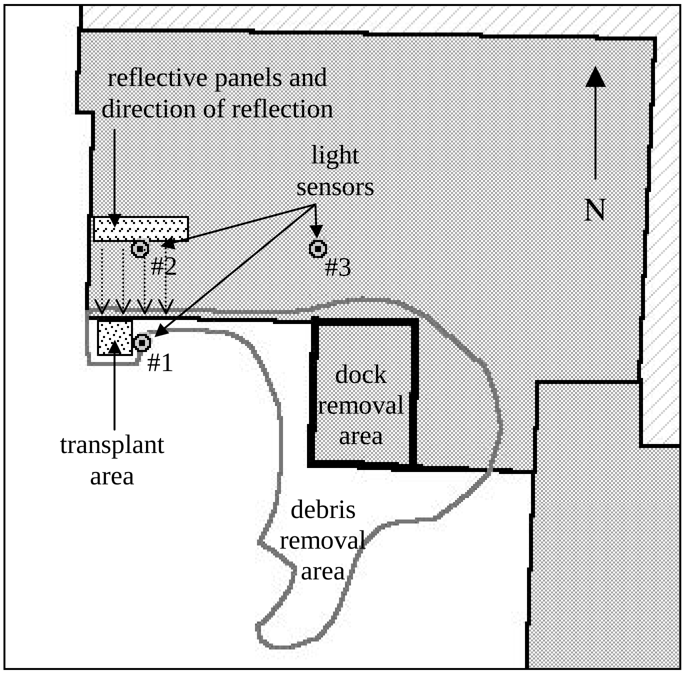

Figure 3. Treatments Location Map

Individual *Z. marina* plants were collected either by using a 6-inch diameter PVC corer (to collect groups of adjacent individuals) or by excavating individuals by hand. The plants were immediately transported to the transplant site. They were then transplanted by either removing a similarly sized sediment core to be replaced by the donor core, or by inserting a finger/hand into the sediments at approximately the same angle as the individual's root orientation, then inserting the plant's roots/rhizomes. Both methods included the gentle tamping/pressing of the marine sediments to help reduce erosion of the disturbed surface sediments. All plants were relocated within two hours of original excavation.

To mitigate for the effect of shading by the new dock construction, the removal of a 36 m^2 section of the existing Gravel dock was constructed in March 1998, following the completion of the new dock construction. In addition, reflective panels were designed and installed beneath the south side of Gravel dock. The objective of these treatments was to increase the submarine light environment to levels adequate for *Z. marina* growth and recolonization.

The 36 m^2 section of dock was removed from the southern most area of the existing Gravel dock (Figure 3). The removal of this section allowed for unobstructed sunlight to reach the submarine environment in the area where debris/rubble had been removed. The combination of full sunlight and newly exposed marine sediments was expected to reinstate the environmental conditions that limited *Z. marina* from existing in that area.

In May 1999, reflective panels were installed beneath a portion of the southern edge of Gravel dock in order to reflect sunlight beneath its southern portion into the submarine environment (Figure 3). Ten panels were placed beneath the dock (Figure 4 and Figure 5); five installed against the underside of the dock (parallel to water surface) and five along the dock pilings (perpendicular to water surface and joined to the five panels placed against the underside of the dock). Each panel was constructed of a standard 4'x8' sheet of plywood and covered on its exposed side with 2.0 mm-thick reflective Mylar-type film. The reflective film was attached to the plywood sheet by nailing small wooden slats onto the surface of the film, attaching it to the plywood sheet in many places to minimize exposure between the plywood and the film, which could damage the film in high winds.

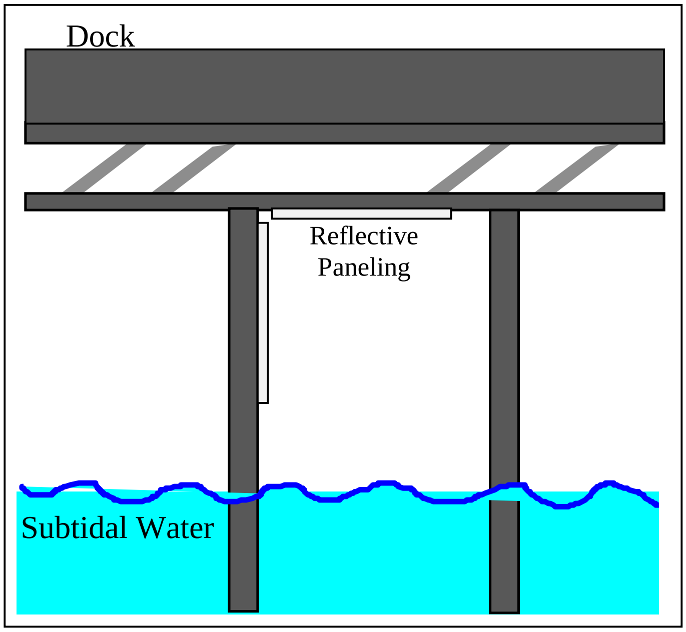

Figure 4. Reflective Panels Schematic

Figure 5. Reflective Panels (photo)

Vegetation Characteristics
A baseline survey of existing vegetation was accomplished by a diver using S.C.U.B.A. immediately following the rubble/debris removal activities and transplant. Subsequent resampling was done during the summers of 1998, 1999, and 2000. Five transects, traversing the existing *Z. marina* population, were established south of Gravel dock. The depths of the transects were randomly chosen between +0.2 m and -1.6 m MLLW (transect A was shallowest; transect E was deepest) (Table 1 and Figure 6). The existing *Z. marina* population is bounded by these depth contours.

Table 1. Transect Depths

Transect	Depth (m; MLLW)
A	- 0.1
B	- 0.4
C	- 0.8
D	- 1.0
E	- 1.3

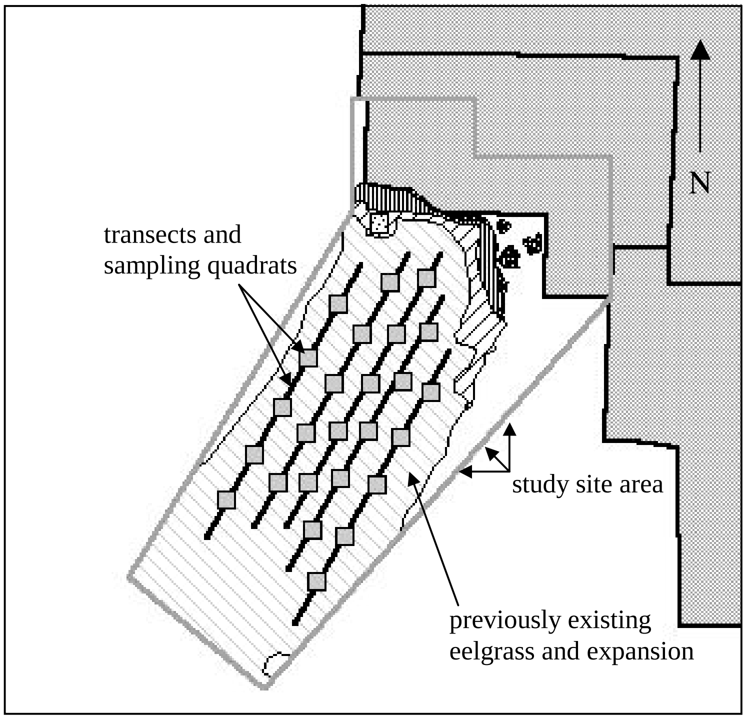

Figure 6. Measurement Transect Locations

Five 0.25 m^2 quadrats were measured along each transect; they were 3 m apart, starting at 1.5 m from the southern end of each transect. At each quadrat, shoot density of *Z. marina* individuals were recorded. During the 1998 sampling, three plants from each quadrat were measured for blade height and width. Estimated aboveground biomass was later calculated.

Areal mapping of the on-site *Z. marina* population was accomplished following the initial restoration/transplant efforts of 1997, and in the subsequent summers of 1998, 1999, and 2000. Mapping was accomplished by a diver using S.C.U.B.A.

Measurement of Physical Parameters
Underwater spherical quantum sensors (LiCor LI-193SA) were placed to measure photosynthetically active radiation (PAR) at canopy height in three locations (Figure 3). Sensor #1 was placed in existing eelgrass cover south of Gravel dock, in full sunlight. Sensor #2 was placed beneath the reflective panels. Sensor #3 was positioned beneath the existing dock where no reflective treatments were installed. Light measurements were made during each consecutive season for a period no less than 10 days, beginning with Spring 2000 and ending Winter 2001. For each seasonal set of measurements, PAR measurements were made every 60 seconds for the duration of the period and mean hourly and daily PAR values were compared.

Results

Alterations to Dock and Environment

A variety of discarded building materials were removed from the intertidal and subtidal areas adjacent to the south end of Gravel dock. The material consisted of broken concrete slabs, discarded chainlink fencing, discarded tires, metal conduit pipe, rubber hose, and various pieces of partially buried rope and cable. In total, approximately 20 m^3 of debris was removed from 70 m^2 of substrate.

In the areas cleared of the debris, *Z. marina* individuals began to recolonize naturally. During each of the three years following the initial debris removal activities, the areal extent of *Z. marina* increased (Table 2 and Figure 7).

Table 2. Areal Increase of Z. marina in Debris Removal Treatment

Year Measured	Increase in Area (m^2)	Mean Density (shoots m^{-2})
1998	32.5	92
1999	Overlapped with Dock Removal and Reflective Panel Treatments	
2000		
	Affected Area (m^2)	Percent Repopulated
TOTAL	70	46%

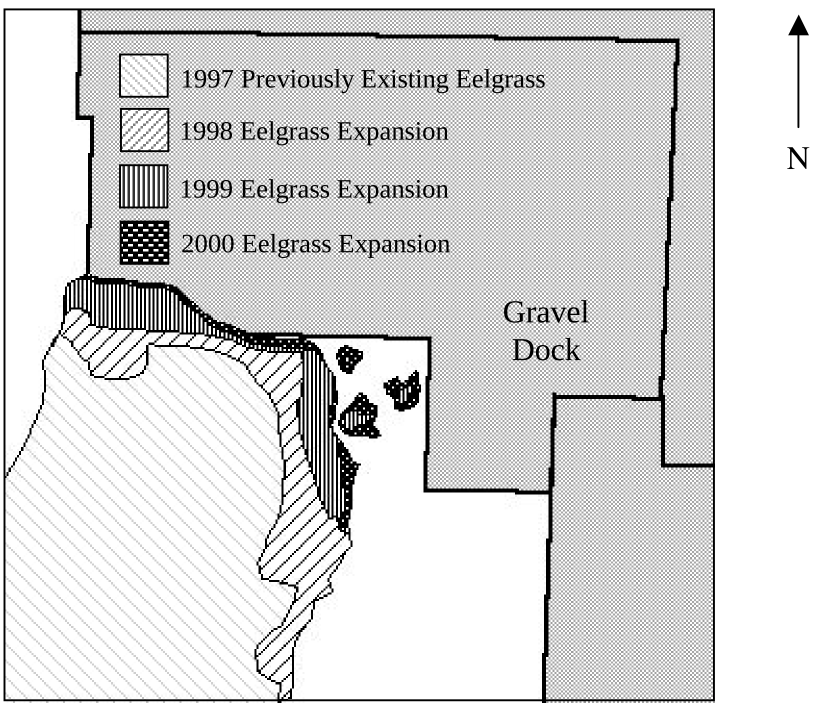

Figure 7. Areal Increase of *Z. marina*

One hundred *Z. marina* individuals removed from a proposed project site were transplanted in a 2.5 m^2 area. Ninety individual *Z. marina* ramets were counted in September 1997 (10 weeks after transplanting). In September 1998, 92 individuals were present. In September 1999, 102 individuals were present. In August 2000, 110 individuals were present (Table 3).

Table 3. Stem count and density of transplants

Year	# of *Z. marina* shoots	Density (shoots m^{-2})
1997	90	36
1998	92	37
1999	102	41
2000	110	44

	Affected Area (m^2)	Percent Repopulated
TOTAL	2.5	100%

The 36 m^2 portion of dock that was removed to allow unobstructed sunlight to reach the submarine environment promoted the natural re-colonization of *Z. marina* into the affected area. During the first year following the dock removal demonstrated rhizomal re-colonization of *Z. marina* into the perimeter of the affected area. During the subsequent years, seed-germinated *Z. marina* individuals naturally established new populations within the affected area and continued to increase in areal extent (Table 4 and Figure 7). After the first year, the newly established *Z. marina* individuals covered 6% of the 36 m^2 area which had the dock removed. After the second year, the *Z. marina* population had grown to cover 17% of the area.

Table 4. Areal Increase of *Z. marina* in Dock Removal Treatment

Year Measured	Increase in Area (m^2)	Mean Density (shoots m^{-2})
1998	Not Yet Removed	
1999	2	27
2000	4	145

	Affected Area (m^2)	Percent Repopulated
TOTAL	36	17%

Beneath the southern edge of Gravel dock, reflective panels were installed to increase the amount of submarine light in the subtidal environment. In the area affected by the panels, approximately 9-11% of full sunlight was reflected into the subtidal waters. In the area affected by dock shading, approximately 1-3% of full sunlight was recorded in the subtidal waters. The results of this increase of submarine PAR led to the natural re-colonization of 18 m^2 of *Z. marina* at an average density of 28 shoots m^{-2} (Table 5). (See *Results: Measurement of Physical Parameters* section for seasonal PAR data)

Vegetation Characteristics

In 1997, prior to the initiation of any restoration treatments, the mean *Z. marina* shoot count for the existing population was 70 shoots m^{-2} (S.E. = 9.36). In 1998, the first year following initial treatments, the mean shoot count was 98 shoots $^1/_4$ m^{-2}. (S.E. = 4.04). In 1999 and 2000, the mean *Z. marina* shoot count was 101 and 97 shoots m^{-2} (S.E. = 6.25 and 10.08 respectively). Overall, the highest density measured was 146 shoots m^{-2} (S.D. = 43.96); transect A (1997) and the lowest was 38.4 shoots m^{-2} (S.D. = 6.68); transect E (1997).

Table 5. Areal Increase of *Z. marina* in Reflective Panel Treatment

Year Measured	Increase in Area (m^2)	Mean Density (shoots m^{-2})
1998	Not Yet Installed	
1999	15	27
2000	3	34

	Affected Area (m^2)	Percent Repopulated
TOTAL	approx. 60	30%

Since the initial mitigation efforts, the overall *Z. marina* areal coverage has increased by approximately 59 m^2 at a mean density of 73 shoots m^{-2} (Table 6). This increase in area includes the transplant site (2.5 m^2), the area beneath the reflective panels (18 m^2), the area from which debris was removed (32.5 m^2), and the area from which the dock was removed (6 m^2).

Table 6. Overall Population Increase and Density of *Z. marina*

Year Measured	Increase in Area (m^2)	Mean Density (shoots m^{-2})
1998	35	85
1999	17	27
2000	7	123
TOTAL TO DATE	*59*	*73*

The area affected by the reflective panels is being populated rhizomatously (clonal) by *Z. marina* individuals found south of the panels in full sunlight. The area from which debris was removed is being populated by *Z. marina* using two reproduction strategies; rhizomes and seeds. Clonal expansion originated from the lower intertidal population found adjacent to the debris removal area, and has progressively invaded from its perimeter. Seedling establishment has initiated within the debris/dock removal area. The newly established seedling populations were not found to be rhizomally connected to the previously existing population or to adjacent seedling populations. The seedling populations hence have rhizomatously expanded since their initial establishment. At the current rate of expansion, they will reach adjacent populations within a few years.

Measurement of Physical Parameters

Seasonal measurement of the submarine light conditions of three locations were conducted during each season for one year. Sensor #2, located beneath the reflective panels, indicated that submarine PAR was approximately 9-11% of full sunlight (measured by sensor #1). Sensor #3, located beneath the dock where reflective panels were not installed, indicated that submarine PAR was approximately 1-3% of full sunlight (Figure 8 and Figure 9). These percentage results were found to be similar for each season while overall PAR was highest during the summer and autumn months. The greatest difference in PAR affected by the reflective panels versus having no panels was greatest during the winter months.

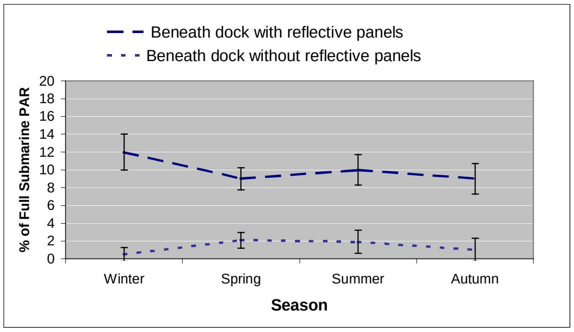

Figure 8. Seasonal Submarine PAR Comparison

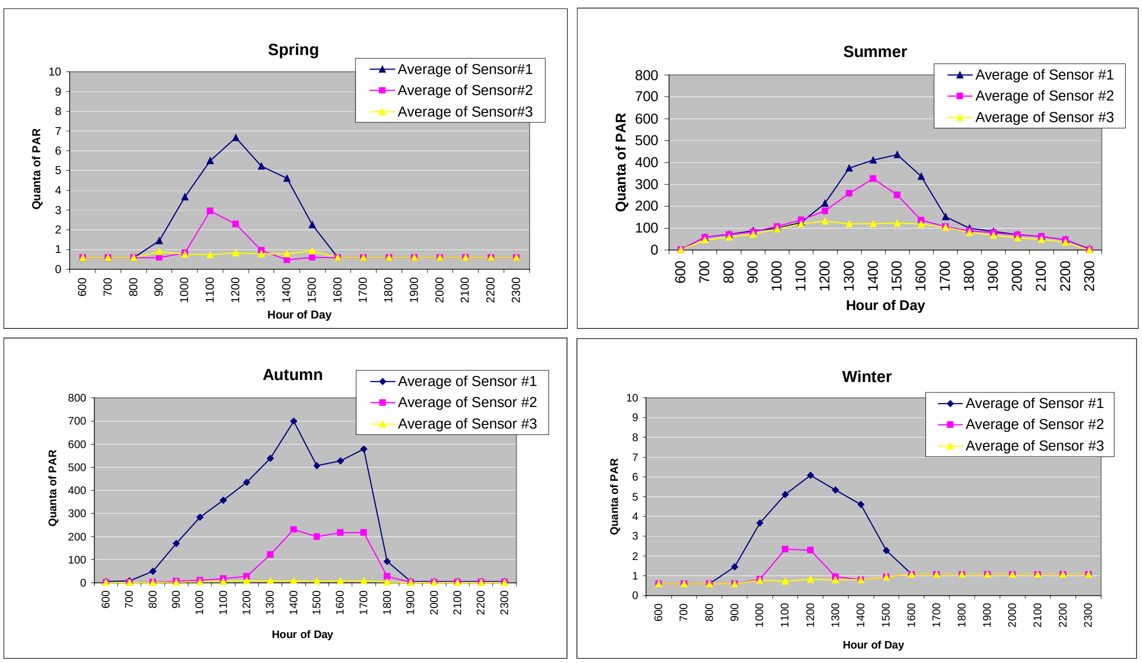

Figure 9. Mean Daily PAR Comparisons

Discussion

This case study utilized a blend of methods for the purpose of creating new *Z. marina* habitat. Due to the limited available area in which to attempt the methods, some of the treatment areas were combined. This combining of methods inherently makes it difficult to clearly define the individual effects of each. In addition, because this site was the only one available for this research, replication was not possible. Repeating these methods at other sites would help to substantiate these results.

Overall, an areal increase of *Z. marina* of 59 m^2 has resulted from using a combination of restoration methods. The most significant results from each treatment immediately followed their installation, with continued *Z. marina* expansion during subsequent years.

As indicated by Tabled 6, the areal increase of *Z. marina* recolonization was highest the year immediately following the debris removal activities. The greatest amount of newly created habitat was exposed to adjacent *Z. marina* populations immediately following this treatment; however, the *Z. marina* population continued to expand in subsequent years. Transplantation of 100 *Z. marina* individuals was accomplished in an area that had been cleared of debris. Largely because of the transplant, density values for the overall site in 1998 are higher than those in 1999.

The high overall density values recorded in 2000 were largely due to the recolonized *Z. marina* individuals within the dock removal treatment area. With the section of dock removed following the removal of debris from the area, two limiting factors (low-light and restricted sediment surface) were thus removed allowing for recolonization to begin. Because this area is in the intertidal area of the site, plants are smaller but more densely spaced. Following their initial seedling establishment in 1999, the population has been rapidly growing in area rhizomatously.

The high transplant success of the 100 *Z. marina* individuals was most likely due to the similarity in site characteristics and proximity to the donor site. The most obvious deterrent to establishment was a piece of rubber hose lodged at one end into the sediment which previously scoured the area as currents moved it across the sediment surface. With its removal, this area was primed for transplant success.

Low levels of PAR are known to be very limiting to *Z. marina* growth (Alcoverro and others 1999, Zimmerman and others 1991). Development of overwater structures, such as commercial docks, have systematically reduced the areal extent of *Z. marina* in coastal marine environments globally (Burdick and Short 1999; Shafer 1999). The installation of the reflective panels beneath Gravel dock, Anacortes, Washington, succeeded in increasing the ambient submarine light environment from 1-3% to 9-11% of full sunlight. This increase in available submarine PAR, while still significantly lower than that of full sunlight, appears to be sufficient to promote rhizomatous recolonization of *Z. marina* in the affected area. The stem density of the *Z. marina* individuals is low, yet the individual biomass appears to be more than adjacent individuals found in full sunlight conditions and at the same depth. This indicates that recolonized *Z. marina* individuals in the affected area have responded to the low level of PAR similarly to those individuals found at deeper depths in full sunlight conditions. At deeper depths, there is less available PAR, and in response, *Z. marina* individuals exist at lower stem densities yet greater individual above-ground biomass.

In addition, the difference in submarine PAR increases with reflective panels versus areas having no panels was greatest during the winter months. This may be accounted for by the lower sun angle during the winter, allowing a greater percentage of full sunlight to reach further beneath the dock. It must be remembered, however, that even though a greater percentage of full sunlight is being reflected into the submarine environment during the winter months, the overall amount of full sunlight is much less than the amount available during the summer months (Figure 8 and Figure 9).

The area affected by the reflective panels is measured as approximately 60 m^2. It is not possible to precisely delineate the area where light conditions are improved by the panels. In addition, between the reflective panels and the southern edge of Gravel dock is dock decking that is not covered by paneling. If this area were also covered, the amount of reflected PAR might increase from current levels, increasing the density of the newly recolonized *Z. marina* individuals.

Acknowledgements

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